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Conventional waterborne hydrographic survey methods have become exceedingly expensive while the need for improvement of charts is increasing rapidly. The U.S. Government is developing techniques to conduct rapid, efficient surveys; especially airborne laser bathymeters. The first system should be in use by 1983. It will penetrate to 28 meters under typical conditions and will be deployed in a helicopter from a coastal survey ship. A hybrid

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system using a combined laser and multispectral scanner is also under development for surveying clear, shoal areas. Advanced high pulse rate laser systems are also under study.

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ABSTRACT

Conventional waterborne hydrographic survey methods have become exceedingly expensive while the need for improvement of charts is increasing rapidly.

The U.S. Government is developing a suite of techniques to conduct far more rapid, efficient surveys; airborne laser bathymeters are foremost among these. The first operational system, the Hydrographic Airborne Laser Sounder (HALS) is now being procured by the Department of Defense, and should be in use by late 1982. It will have a depth capability of 28 meters under typical conditions and will be flown in a helicopter from the Navy coastal survey ships. Development of a hybrid system, which uses a pulsed laser to calibrate an airborne multispectral scanner with respect to depth, has begun for surveying extensive clear, tropical shoal areas. Advanced very high pulse rate active laser systems are also under study.

INTRODUCTION

In the U.S., the Defense Mapping Agency (DMA) is responsible for providing navigational information on foreign and international waters to all United States shipping, both civil and military. Our National Ocean Survey (NOS) has similar responsibility for U.S. coastal waters -- which is now taken to be on the order of 200 miles offshore -- and includes the U.S. islands in the Atlantic and Pacific. Even if all of our charts were completely adequate, and if we continue our data exchange agreements with other countries -- which we have every expectation of doing -- just our necessary maintenance surveys would be an enormous task. As it is, a majority of the DMA charts are less than fully adequate, and NOS also has a substantial survey backlog, especially in Alaska and the Pacific islands. The situation is magnified by a rapidly increasing need for complete, accurate chart coverage. Fuel costs demand the most efficient ship routing, which can now be assisted by satellite navigation systems and weather forecasting. Ships' drafts have greatly increased. In a few years, the NAVSTAR Global Positioning System (GPS) will allow ships to navigate so accurately that many existing charts will be far more inadequate than they are now; landfalls and other piloting operations will be confusing to the point of genuine hazard. In addition to all those factors, the complexities of international commerce and politics can require change in ship movements, that are often difficult to predict, through poorly charted areas. All of these things make a drastic improvement in hydrography a real necessity.

NOS, actually, has managed to sustain its part of the effort reasonably well. They have a sizeable fleet of ships and launches, their own uniformed

officer corps (who become part of the Navy in wartime) and a large complement of civilian surveyors and engineers. They are altogether a highly specialized professional organization and accomplish a lot with the resources available to them. In recent years, they, like everyone else, have been handicapped by inflated expenses and they have sought a means of increasing survey efficiency, i.e., a way to collect more data faster and cheaper. To this end, they have begun a modest photogrammetry program, which has been successful but obviously only a partial answer. It is limited to shallow, clear water and data reduction is still very laborious. They are also outfitting two of their ships with new multibeam sonar equipment which shows considerable promise. Over the last several years, a number of people at NOS have seen that airborne laser bathymetry could be used for quickly and cheaply surveying close inshore areas, which are always disproportionately expensive and time-consuming--and frequently dangerous-- to survey with launches. They have studied that technology carefully and presented a detailed analysis to their management.

Within our Department of Defense, hydrography did not fare quite so well for a while. Having to compete with extremely high weapon system and personnel costs, and not being nearly as visible, military hydrography shrank severely over a period of several years. At this point, our coastal survey operation is down to one 400-foot ship, USNS CHAUVENET, and her four 36-foot launches. (CHAUVENET is currently in Indonesia surveying the Makassar Straits area.) Inasmuch as DMA's fundamental survey backlog amounts to about 200 ship years of work at the present rate, the situation has become quite serious and, if some action were not taken, would be likely to remain so, with all the attendant implications.

Fortunately, the problem has been recognized and is being dealt with. To start, there have been reorganizations within both DMA and the Navy to bring the correct expertise to bear. Plans exist to recommission CHAUVENET's sister ship, HARKNESS, and to let some commercial survey contracts.

At the same time, and of greatest significance, we have established a research and development program to produce a suite of tools which will collect and process data orders of magnitude more efficiently. The program includes various satellite sensors, notably the Landsat multispectral scanners; airborne systems; and improved acoustic sensors, which we will always need to survey those waters too deep and/or opaque for use of electro-optical methods. Automated digital data reduction, storage and retrieval and chart production techniques are under development to use the immensely increased volume of data which will result.

It is the airborne laser system that we are counting on for a near term increase in survey rate, however. Landsat is beginning to be very helpful in detecting and correctly locating features, within its 80 meter resolution capability, but it will be a number of years before we can use it to calculate depths with much accuracy. The sonar developments will probably not be completed for another five years, and our other airborne techniques, the hybrid active/passive multispectral scanner-laser system could also take nearly that long, depending on budget decisions.

BACKGROUND

Laser bathymetry has been under consideration in the U.S. for about fifteen years, beginning with the early basic studies supported by our Office of Naval Research (ONR) at Syracuse University. During the late sixties and early seventies, our Naval Oceanographic Office (NAVOCEANO) conducted extensive engineering feasibility experiments. These tests were highly encouraging, but some of the key technologies -- notably automatic data processing -- were not mature enough to allow development of a cost effective operational system. Later, in the mid-seventies, some former Oceanographic Office people, then at the Naval Ocean Research and Development Activity (NORDA), tried an approach which would combine photogrammetric and laser bathymetry techniques but this, too, proved uneconomical. Meanwhile, about 1973, our National Aeronautical and Space Administration (NASA), under its charter to transfer space related technology to other applications, began development of their Airborne Oceanographic Lidar (AOL), a laser device intended for both bathymetry and fluorosensing. Some NOS engineers, also aware of the Navy work, arranged a joint study with NASA of the bathymetry application. A year or so later, DMA and the Navy joined the effort. Flight tests were held in late 1977 on some offshore Atlantic shoals and in the Chesapeake Bay. The results, while not absolutely conclusive regarding accuracy, provided a strong indication of what could be produced which would rapidly, accurately and safely survey shallow water at a fraction of the cost of launch operations.

HALS DEVELOPMENT PROGRAM

In view of the compelling need to improve our coastal hydrography effort, DMA decided to proceed. NORDA, under DMA oversight and funding sponsorship, was designated to manage the project, including writing the specifications and contracting the actual design, fabrication and initial testing. NOS was to assist with the studies and analyses of which they are uniquely capable, at the same time considering how the DMA system could be adapted for their own operational requirments. In order to minimize costs, as well as to improve our survey rate as soon as possible, it was decided to push the state of technology the relatively small amount necessary to achieve an operationally capable prototype rather than simply an advanced development model beyond which an operational system would have to be produced. The confidence to attempt this was derived from past Navy experiments and NASA and NOS' work with the AOL, as well as the considerable knowledge gained by the Naval Air Development Center (NADC) in their studies of the use of airborne lasers for locating submarines. A great deal of care and time was taken in developing the specifications for the system, which was to be called the Hydrographic Airborne Laser Sounder (HALS). Much specific effort was given to forecasting operational requirements; maximum communication for this purpose was established with NAVOCEANO, whose task it is to ~~actually~~ conduct hydrographic surveys for DMA. ONR, NADC and NASA were also closely involved. It took well over a year to evolve the specification, but it is expected that the investment will prove to be more than sound.

There were several basic constraints within which HALS had to be designed. The data have to meet International Hydrographic Bureau (IHB) accuracy

standards and be compatible with production processing; the system must have sufficient depth capability to justify development; operational costs must be kept within budget; and the operation must be eye safe to observers. The most important areas of technology advance needed to achieve these goals were developing a laser of requisite pulse length, repetition rate and power, and accounting for errors related to the geometry of the laser energy propagation in the water and through the surface.

Initially, HALS will be employed in the helicopter carried by the CHAUVENET class ships for support of their radio navigation aid sites ashore. This has disadvantages related to the size, vibration and low speed of these aircraft, but is necessary because of the normal remoteness of our survey areas from airfields from which fixed wing planes could operate. An advantage will be close coordination of the airborne operations with those of the boats and ships. Besides, the HALS will have to use the same shore based navigation net as the ships until GPS becomes available in the late eighties. While it is recognized that this interim scenario will not allow use of HALS to its full potential, analysis shows that addition of the airborne system to the surface surveys will permit, under typical turbidity and depth conditions, collection of about 30% more data at approximately the same cost ~~per mile~~ as the present operation. With the cost of shiptime as high ~~enormous~~ as it is, this will be well worthwhile.

A contract for the design, fabrication and testing of HALS was let in late 1979 to AVCO Everett Research Laboratories, Inc., of Everett, Massachussetts; the design phase was completed in mid-1980 and fabrication

commenced. Laboratory testing of the completed system and subsequent delivery to NORDA for technical evaluation is expected in early 1982. NAVOCEANO will receive HALS for operational evaluation and shakedown employment by, hopefully, October of 1982.

NOS PROGRAM

NOS meanwhile has concentrated on the above mentioned analyses, related largely to signal processing, light propagation modelling and horizontal positioning, in support both of HALS and a possible system of their own. An NOS system would be similar to HALS, taking advantage of the basic design, but with more rigorous horizontal accuracy requirements -- for their more frequent large scale surveys -- and employed in a fixed wing aircraft. Whether NOS' budget will permit them to build a system soon seems, unfortunately, somewhat in doubt. It may be, however, that HALS could be used to satisfy some NOS survey requirements as well as for DMA.

NASA

NASA has kept the AOL flying for various experimental purposes since 1977. Its primary use has been for surface wave spectra and shoreline mapping and the fluorosensing application. Experiments are planned for nearshore/beach profiling and the locations of schooling fish, as well as inland terrain mapping.

ACTIVE/PASSIVE TECHNIQUE

Another laser bathymetry technique which we have considered for some time is a hybrid system in which sunlight reflected from the ocean bottom is received by a multispectral scanner and periodically calibrated with respect to depth by a pulsed laser. This approach has been studied for amphibious warfare reconnaissance by the Naval Coastal Systems Center (NCSC). It is less accurate, is limited to the depth capability of the passive scanner, and requires specific ambient lighting conditions. It would come close to meeting IHB standards under many circumstances, however, and provide -- depending on field of view and altitude -- near photographic resolution. Installed in a fast, long range fixed wing aircraft, it should be extremely valuable for surveying the vast, complex clear water tropical areas. Precise positioning will have to await GPS or improvements in inertial navigation systems -- or some combination thereof -- although it should also be possible sometimes to digitally register the airborne MSS data to Landsat imagery.

We were about to -- reluctantly -- decline this option as being of reconnaissance value only, since it would generally not achieve IHB accuracy. However, DMA decided to seriously consider publishing certain charts in a format which would permit use of high reconnaissance quality surveys, in areas where that would be an improvement over present data; ranges of depth in specific areas would be portrayed vice discrete individual soundings. With this decision, the hybrid, or Active/Passive,

technique was included in the R&D program. We have begun a preliminary design phase to optimize an exisitng experimental system for bathymetry, which is paced with a parallel computer emulation effort to determine how the enormous data throughput can best be handled. Results of the data processing study are expected in early 1982; the remaining development will hopefully proceed rapidly from there, assuming the new chart presentation meets with expected approval by navigators.

ADDITIONAL DEVELOPMENTS

With the change in charting philosophy under discussion, it is also seen of course that the pre-GPS HALS could be put to considerably more use in a fixed wing aircraft for collection of good reconnaissance quality data, although its highest priority employment would still be in areas where compliance with IHB accuracy standards is needed. Such areas would include those of possible naval operations, harbors, approaches, etc. Looking to a next generation active laser system, we are watching the development of high pulse rate laser technology, including metal vapor lasers which should pulse at a rate of the order of 6000 Hz. Such a transmitter, flown in a high speed aircraft, with necessary attendant advances in data processing and navigation, would be able to survey at a rate difficult at present to imagine. In our long range R&D program, we envision commencing serious development of an operational high pulse rate active laser system about 1986.

Another important consideration related to airborne bathymetry is the recording of the tidal cycle during the survey in order to relate the

bathymetry to the local tidal datum. *The concept currently envisioned is* an expendable, air deployable telemetering hydrostatic pressure tide gauge. The various pieces of technology appear to be available to do this, but the synthesis would of course be non-trivial and cost will be a major factor. We have just begun to study this problem, but hope to evolve a design within a year or two.

CONCLUSION

As is evident from the investment we are making, we in the United States are relying heavily on airborne electro-optical technology to make a profound improvement in our hydrographic survey operations.